Estimate of chickpea production (*Cicer arietinum* L.) as a function of plant phenology

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Abstract

Chickpea is a crop of the indeterminate type which can be an advantage to estimate in advance the production of this crop. The lack of water, cold or heat are the most limiting factors for the success of this culture; in the emergency phase, situations of waterlogging or extreme drought lead to an irregular installation of the culture, on the other hand, drought, excess water and extreme heat during the reproductive period, cause floral abortion and/or shorter cycles, and consequently, smaller income. Chickpea yield essentially depends on the number of seeds per unit area, which in turn depends on the length of the reproductive period. This is a problematic situation that proves the complexity of estimating the yield in leguminous crops in relation to species of determined habit. We try to know the dates of development of chickpeas, namely when the vegetative apex becomes reproductive (Beginning of Flowering, BF) and when the last flower of the apex no longer develops (End of Flowering, EF), this knowledge is fundamental anticipate and estimate the productive potential. Portugal is a country with a typical Mediterranean climate that has high capacity to produce grain legumes and the chickpea breeding program started at Plant Breeding Station, Elvas, Portugal in 1986. Since this data we have determined the dates of the BF and EF and, due to the difference between the two, the Reproductive Period (RP); the longer this period, the greater the number of pods and seeds per plant, and, as a consequence, greater final productions. In this way, over the course of 24 years, we have been recording the dates of entry into flowering and the end of flowering according to the thermal sum in Growing Degree Days (GDD) of by genotype, by trial and by year. In this analysis it was found that the BF is achieved when the sum of the GDD reaches 757 ºC, for maximum temperatures of 23 ºC, and the EF for sums of 1224 ºC and maximum temperatures of 30 ºC, that is, when temperatures above 28 ºC are registered, for two or three days in a row, is an indicator that the EF is approaching. It may happen later if precipitation occurs when the temperature reaches those values, but it varies from genotype to genotype. The new varieties, Elipse, Electra, Eleia, Eladir and Elfo confirm this situation, with the ELEIA variety standing out earlier in flowering.

Keywords: growing degree days, phenology, *Cicer* genus, production.

Estimativa da produção de grão-de-bico (*Cicer arietinum* L.) em função da fenologia da planta

Resumo

O grão-de-bico é uma cultura do tipo indeterminado que pode ser uma vantagem para estimar antecipadamente a produção desta cultura. A falta de água, frio ou calor são os fatores mais limitantes para o sucesso desta cultura; na fase de emergência, situações de alagamento ou seca extrema levam a uma instalação irregular da cultura, por outro lado, seca, excesso de água e calor extremo durante o período reprodutivo, causam aborto floral e/ou ciclos mais curtos e, consequentemente, menores rendas. A produção do grão-de-bico depende essencialmente do número de sementes por unidade de área, que por sua vez depende da duração do período reprodutivo. Esta, é uma situação problemática que comprova a complexidade de se estimar o rendimento em leguminosas em relação a espécies de determinado hábito. Procuramos conhecer as datas de desenvolvimento do grão-de-bico, nomeadamente quando o ápice vegetativo se torna reprodutivo (Início da Floração, IF) e quando a última flor do ápice já não desenvolve (Fim da Floração, FF), este conhecimento é fundamental antecipar e estimar o potencial produtivo. Portugal é país de clima tipicamente mediterrânico com elevada capacidade de produção de leguminosas-grão. O programa de melhoramento desta espécie iniciou-se na Estação de Melhoramento Plantas, Elvas, Portugal em 1986. Desde esta data, determinamos as datas do IF e FF e, por diferença das duas, o Período Reprodutivo (PR); quanto maior for este período maior será o número de vagens e de sementes por planta, e, como consequência maiores produções finais. Deste modo, e ao longo de 24 anos, fomos registando as datas de entrada em floração e o fim de floração em função da soma térmica em Graus-dias de crescimento (GDC) por genótipo, por ensaio e por ano. Nesta análise constatou-se que o IF é conseguido quando a soma dos GDC atinge 757 ºC, para temperaturas máximas de 23 ºC, e, o FF para somas de 1224 ºC e temperaturas máximas de 30 ºC, isto é, quando se regis tam temperaturas superiores a 28 ºC, por dois ou três dias seguidos, é um indicador que o FF se está a aproximar. Pode acontecer mais tarde se ocorrer precipitação quando a temperatura atinge aqueles valores, sendo porém variável de genótipo para genótipo. As novas variedades, Elipse, Electra, Eleia, Eladir e Elfo confirmam esta situação e destaca-se a variedade ELEIA mais precoce na entrada em floração.

Palavras-chave: graus-dias de crescimento, fenologia, gênero *Cicer*, produção.

1. Introduction

Chickpeas belong to the order Rosales, family Fabaceae (International Code of Botanical Nomenclature – St. Luis Code, 1999), subfamily Lotoideae (first classified in tribe *Vicieae* and currently in tribe *Cicereae* Alef. Kupicha), genus *Cicer* L. and species *Cicer arietinum* L. (Van der Maesen, 1972, 1987).

Chickpea was one of the first grain legumes to be domesticated in the Old World (Europe, Asia and Africa) and according to De Candolle (1882), (cit. in. Van der Maesen, 1972), based on the philology of the names that had been attributed to culture and botanical and historical data, the region of origin is located between Greece and the Himalayas, south of the Caucasus and north of Ethiopia. Vavilov (1926) (cit in. Van der Maesen, 1972) indicated as main centers of diversity, Southeast Asia (subdivided into the centers of India, Central Asia, and the Near East (Vavilov, 1926 cit in. Zohary, 1970 and Vavilov, 1997)) and the Mediterranean. It also considered a secondary diversity center in Ethiopia (Abyssinian Centre).

Chickpea is an annual, shrubby, xerophytic plant rarely growing above one meter (Cubero, 1987). Its xerophytic character is present in the glandular pubescence of the stems, leaves, calyxes, pods, and roots (Van der Maesen, 1972). The roots are robust and long, rich in starch in the parenchymal tissue. Deeper roots can play an important role against soil erosion (Van der Maesen, 1972). Chickpea plants, normally with an erect habit, however, can have different types, depending on the number and type of branches: tree-shaped, bush-shaped, and prostrate types. The stems are branched with 20 to 75 cm long (Van der Maesen, 1972) developing leaves from the base.

Portugal grows two types of chickpeas (Desi type with small seeds, coloured and angular shape, and Kabuli type, with large and beige colour seeds and ram-head shape). More than 80% of the world production of chickpea is Desi type, predominantly grown in subsistence agriculture systems (FAOSTAT, 2022).

One of the main characteristics of the chickpea is the indeterminate type of the plants, verified in the continuous growth of the apex (Figure 1), as long as the atmospheric conditions allow it.

Figure 1. Indeterminate type of chickpea plants (desi-colorful flowers and kabuli-white flowers type). Source: Author, 2023.

The lack of water, cold or heat are the most limiting factors for the success of this culture; in the emergency phase, situations of waterlogging or extreme drought lead to an irregular installation of the culture, on the other hand, drought, excess water, and extreme heat during the reproductive period, cause floral abortion and/or shorter cycles, and consequently, smaller income (Cubero, 1987; Duarte-Maças, 2003). Chickpea yield essentially depends on the number of seeds per unit area, which in turn depends on the length of the reproductive period (Allard, 1960; Duarte-Maçãs, 2003).

This is a problematic situation that proves the complexity of estimating the yield in leguminous crops in relation to species of determined habit. Knowledge of chickpea development dates, namely when the vegetative apex becomes reproductive (Beginning of Flowering, BF - number of days after sowing, up to 5% of the plants in the plot have flower buds) and when the last flower at the apex no longer develops (End of Flowering, FF - number of days after sowing, until the last flower forms), it is essential to anticipate and estimate the productive potential.

Portugal is a small country with a typical Mediterranean climate that has high capacity to produce grain legumes and the chickpea breeding program started at INIAV (National Plant Breeding Station, Elvas, Portugal) in 1986 and is essentially based on plant germplasm received from ICARDA, ICRISAT, Australia, Turkey… and local Portuguese populations.

A breeding program involves many disciplines (Allard, 1960) to be able to find an ideal plant and be able to apply for the National Variety Catalogue (Figure 2).

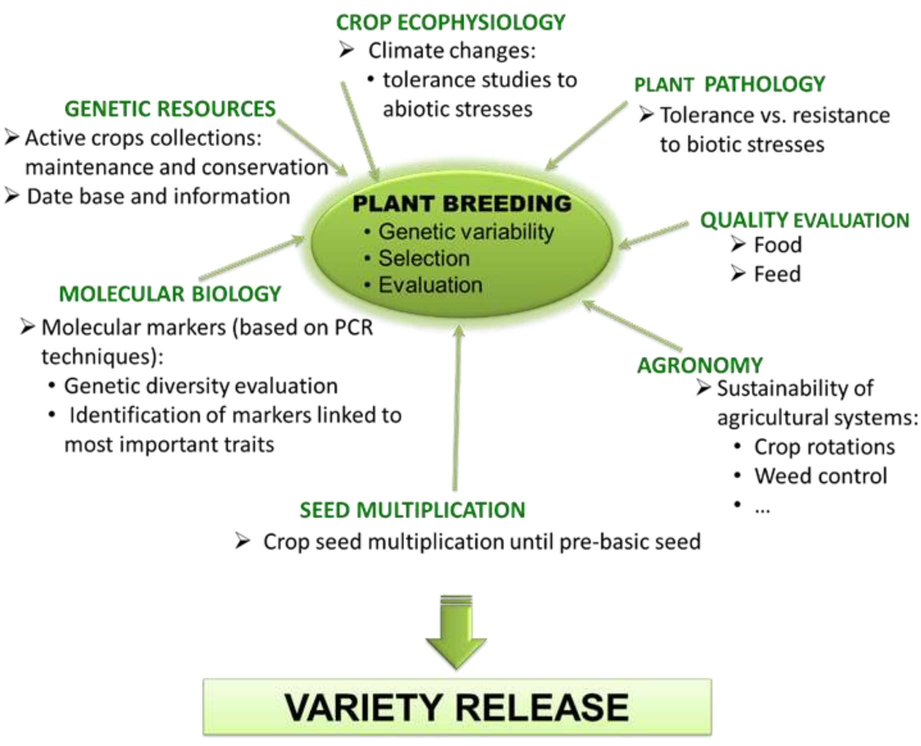

Figure 2. Chickpea breeding Program in Portugal started in 1986 (Duarte, 2022).

Our plant breeding program (Duarte et al., 2001) it is mainly to develop chickpea lines/genotypes were the main objective is to obtaining new varieties adapted to early autumn/winter that increase yield potential: autumn where chickpea plants have favourable atmospheric conditions; sowing dates during March yield approximately 500 kg/ha^{-1}, meanwhile sowing date during November/December improves yield up to 2500 kg/ha^{-1} (Figure 3); the plants develop more biomass, flowers and pods), crops with high tolerance to Ascochyta blight, frost at seedling stage, drought tolerance and early maturity in the final stages of the cycle and tall plants (to allow full mechanization of the crop) with seeds of medium to large size.

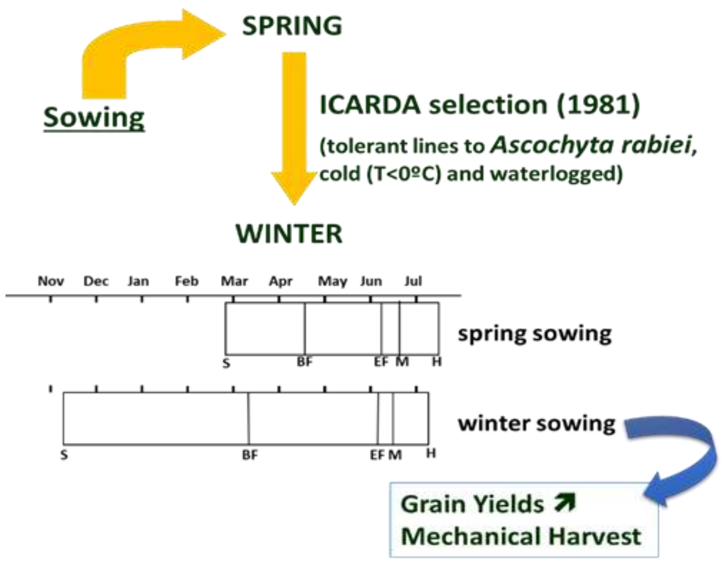

Figure 3. Advantages of autumn/winter sowing compared to spring sowing (S-sowing date; BF-beginning of flowering; EF-end of flowering; M-maturation and H-harvesting). Source: Author, 2023.

INIAV, Elvas, Portugal currently has 11 varieties registered in the Portuguese Variety Catalogue (CNV). With this work we seek to help farmers understand the crop in relation to its phenological process and prevent situations of atmospheric irregularities, namely temperature and precipitation fluctuations.

2. Materials and Methods

This study references data since the beginning of the genetic improvement program of the chickpea crop (1994/95) until now. To understand and interpret the results, it is necessary to know the climate of Elvas (typically Mediterranean) with great fluctuations in precipitation and maximum temperature over the years presented on (Figure 4).

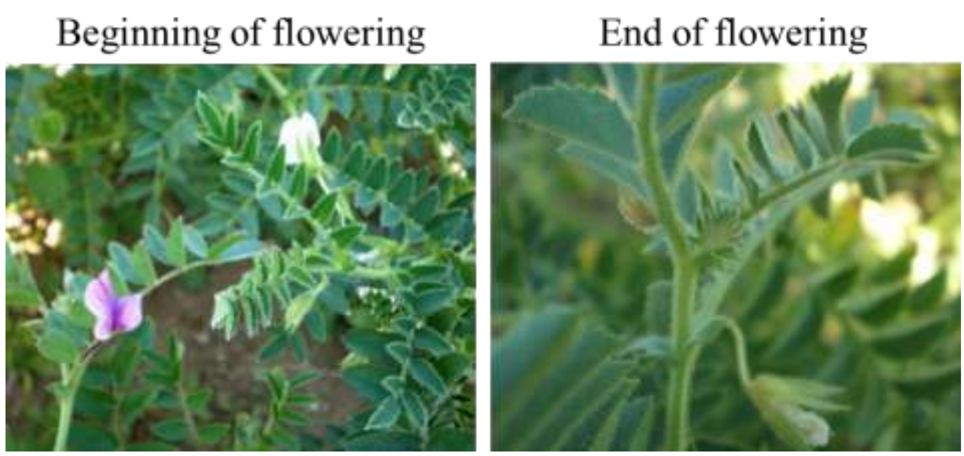

Figure 4. Photos of the two phenological stages: Beginning, and End of Flowering. Source: Author, 2023.

For this analysis, the dates for the Beginning of Flowering (BF), End of Flowering (EF) (Figure 5) by difference of the two - Reproductive Period (RP) were collected. The longer this period (RP), the greater the number of pods and seeds per plant, and, as a consequence, greater final productions

In this way, and over 24 years, we registered the dates of flowering and the end of flowering as a function of the thermal sum in Degree-Days of Growth (GDC = Tªaverage -4 ºC), by genotype, by trial and by year in tests carried out at INIAV in Elvas (Table 1).

Table 1. Degree-days of growth (GDC = T^{a}average -4 °C).

Years	Mean Temperature	GDC
1994/95	17.3	13.3
1995/96	17.3	13.3
1996/97	17.1	13.1
1997/98	17.6	13.6
1998/99	17.3	13.3
1999/00	15.5	11.5
2000/01	17.3	13.3
2001/02	16.5	12.5
2002/03	17.2	13.2
2003/04	17.1	13.1
2004/05	17.2	13.2
2005/06	17.0	13.0
2006/07	17.1	13.1
2007/08	17.0	13.0
2008/09	17.1	13.1
2009/10	17.8	13.8
2010/11	17.5	13.5
2011/12	16.8	12.8
2012/13	16.4	12.4
2013/14	17.2	13.2
2014/15	17.7	13.7
2015/16	17.5	13.5
2016/17	18.0	14.0
2017/18	17.1	13,1
2018/19	17.5	13.5
2019/20	16.9	12.9
2020/21	17.2	13.2

Source: Author, 2023.

To confirm the results and better understand the phenology and response of plants to the environment, we analysed only the most recent varieties. This data were statistically analysed in the MSTAT-C (Microcomputer Program for the Design, Arrangement, and Analysis of Agronomic Research; Michigan State University East Lansing, East Lansing).

3. Results and Discussion

The chickpea genetic breeding program, as mentioned above, began in the 1985/86 agricultural year, and as is expected in the Mediterranean climate, climatic conditions are very variable from year to year, and the production to be obtained is not predictable annually.

The period of years of our experimentation was very different, with very hot, dry, cold, and humid years happening at any stage of the vegetative cycle. The first results are shown in Table 2 where we present how environmental conditions influences chickpea yield in Portugal (National Plant Breeding Station, Elvas) for 35 years, in autumn/winter sowing.

Daily records of meteorological data are very important to predict water deficit in order to understand the plant responses. For example, the occurrence of precipitation after a dry period promotes, in legume crops, like chickpea, flower dropping, pod abortion with a consequent decrease in grain yield (Duarte, 2022). For these crops with an indeterminate type of growth and under Mediterranean climate pattern where intermittent drought is common, is very difficult to predict yield and the use of crop models doesn't work.

Table 2. Climatic data and chickpea grain yield at the National Plant Breeding Station (Elvas) for 35 years, in autumn/winter sowing (more mean and standard deviation).

Year	Total Precipitation	Winter Precipitation	Precipitation			Max, Temperature Absolute						Grain Yield
			March	April	May	March	Days > 27º	April	Days >27º	May	Days > 27º	(kg/ha)
1985/8	365.4	284.2	21.7	42.8	12.3	21.5		23		36	17	1383
1986/8	488.8	240	10	95.9	2.7	26.5		27		35	24	1240
1987/8	659.7	350.6	13.8	32.5	29	24.7		26.6		29	2	2800
1988/8	433.9	181.4	26.8	69.6	25	25.5		22		32	14	1900
1989/9	806.9	511.7	27.1	115.1	25	25.5		23.6		33	11	3000
1990/9	524.3	285.6	96.4	30.6	11	24		26.5		34	18	1750
1991/9	383	101.2	0	62.9	11	29	2	29.5	5	35	20	750
1992/9	384.4	181.9	51.3	52.9	25	23		28	1	24.6		3150
1993/9	432.8	218.5	7.5	10.2	25	27.5	1	30.5	4	33.5	9	825
1994/9	330.2	161	13	9.8	29	26.5		31	10	32.8	20	952
1995/9	824.6	624.6	57.2	29.3	30	24.5		26.5		35	8	1810
1996/9	676.7	456.2	0.1	30.1	59.7	28.5	5	32	9	32.5	5	625
1997/9	757.9	515.3	10	36.8	95	27	1	27	1	30	7	850
1998/9	232.1	91.9	63	16	23.6	24		30.5	10	35	14	820
1999/0	463.4	56.1	14	140.6	26	26		22		34	11	1360
2000/0	765.6	558.7	127.1	0.4	58	23.2		26		36.5	11	800
2001/0	435.5	116	90.2	50.8	17.1	28.5	3	31	6	34	13	1500
2002/0	495.2	300.8	41	55.4	6.2	25		26		34	23	1250
2003/0	578.4	279.8	23.2	23.3	57.8	24		30.5	4	29.5	14	950
2004/0	285.9	45.7	31.7	10.1	43.1	26.5		31	4	34	18	920
2005/0	487.1	154.4	89.4	28	11	26		27.5	3	37.5	23	1120
2006/0	653.7	298.6	6.6	34.8	38.5	22.5		27.5	2	34.5	10	1000
2007/0	423.3	269.2	8.2	87.1	28	24.5		30	7	30	4	3020
2008/0	311.5	240.8	9.4	34.7	6,9	27	1	28	1	37	17	1014
2009/1	806.8	575	98.6	66.6	80	22		30.5	3	33	7	524
2010/1	656.7	412.7	61	45	40	27.6	1	26.3		34	10	820
2011/1	269.7	185	2.1	4.5	75	27.6	1	26.3		37.5	19	652
2012/1	520.8	387.3	116.2	9.6	75	19.9		29.8	4	31.7	14	730
2013/1	542.2	403.4	19.5	79.4	69	26.5		31	6	33.5	20	680
2014/1	534.4	362.5	20.5	110.3	2.8	28.2	3	30.2	6	38.3	27	724
2015/1	600.5	370.8	29.2	80.6	119.7	21.5		25.7		32.8	7	697
2016/1	462.6	337.1	61	2	26.2	26.4		30.4	11	35.7	17	820
2017/1	592.5	200.6	129	95	37	24.8		30.2	3	30.2	9	1400
2018/1	368.4	265.9	12.5	68.3	4.9	26.7		29.7	2	35	21	882
2019/2	565.1	278.2	75.9	158.7	29	25.7		25.5		34.9	16	1022
2020/2	599.6	446.6	18.7	83	9.9	25.2		30.1	1	34.4	11	1700
Mean	520.0	298.6	41.2	52.9	35.1	25.4		28.0		33.6		1262.2
sd	156.7	147.1	37.9	39.1	27.7	2.2		2.7		2.7		705,5

Source: Author, 2023.

Rainier years flower later, as the cycle becomes longer. However, they do not necessarily have greater production. Higher yields are obtained under conditions of not excessive precipitation during the late reproductive period, such as maximum temperatures not exceeding 28-30 °C.

During this period (35 years), grain yields vary from 524 to 3150 kg/ha^{-1}, showing that high yields can be obtained in seasons with high or low rainfall amount depending on distribution during spring. For some wet seasons grain yield is mostly limited by diseases as Ascochyta rabiei or Fusarium oxysporum, showing that are too many other factors that contribute to the determination of grain yield (Duarte, 2022). When correlations are performed among different climate variables (maximum temperature and precipitation) the results clearly show the difficulty in explaining yield variability among seasons based on those parameters and grain yield (Table 3).

Table 3. Correlation analysis (r) between grain yield and maximum temperature and rainfall during the reproductive period of chickpea plants (winter sowing).

	Precipitation	Max. Temperature
Grain yield vs. total precipitation	0.1067	
Grain yield vs. Winter precipitation	-0.0057	
Grain yield vs. March	-0.0613	-0.1598
Grain yield vs. April	+0.2509	-0.3280
Grain yield vs. May	-0.5139	-0.5368

Source: Author, 2023.

These situations resulting information to help the breeder's and farmers to understanding that higher temperatures and precipitation during the month of May (when temperatures can already reach values of 35 ºC), lead to pod abortion and a great loss of yield.

Table 4 and Figures 6 and 7 corresponding to the beginning and end of flowering respectively in trial's data from 24 years of breeding program. Before 1994/95 we only recorded average flowering (when 50% of the plot has flowers).

Table 4. Relates the Growing Degree Days (GDD = Mean -4 ºC for chickpea). Data are from long term trials at Elvas, from 1994/95 until now.

Year	BF	Rainfall*	TMax*	EF	Rainfall**	TMax**
1994/1995	797	106	19.8	1100	0	31
1995/1996	845	536	24.5	1140	24	26.5
1996/1997	792	350	24.6	1000	0	27.6
1997/1998	770	252	23	1144	41	27
1998/1999	782	112	24	1383	53	29
1999/2000	718	49	24	1102	127	28
2000/2001	784	580	18.5	1372	69	26
2001/2002	637	176	26.5	1096	66	30
2002/2003	810	300	24.5	1373	102	27
2003/2004	796	244	15	1489	24	30.5
2004/2005	735	55	19	1244	18	29
2005/2006	771	235	21.5	1190	22	27.5
2006/2007	825	168	22.5	1459	78	33
2007/2008	804	153	29.5	1208	87	30
2008/2009	761	211	23	1363	34	29
2009/2010	837	595	22	1571	118	30.5
2012/2013	634	243	27.3	1033	7	31.7
2013/2014	845	326	17.7	1313	51	32.5
2014/2015	689	72	30.2	1184	113	35.2
2015/2016	796	147	20.1	1304	128	30.2
2016/2017	679	164	26.6	1119	10	31.5
2017/2018	791	412	22.6	1088	29	27.8
2018/2019	638	64	26.7	1267	66	33.3
2019/2020	633	113	25.7	1128	175	32.1
Means	757	236	23	1236	60	30

Max	845	595	30	1571	175	35
Min	633	49	15	1000	0	26

Note: *Period considered: from sowing to March. **Between April and July. Source: Author, 2023.

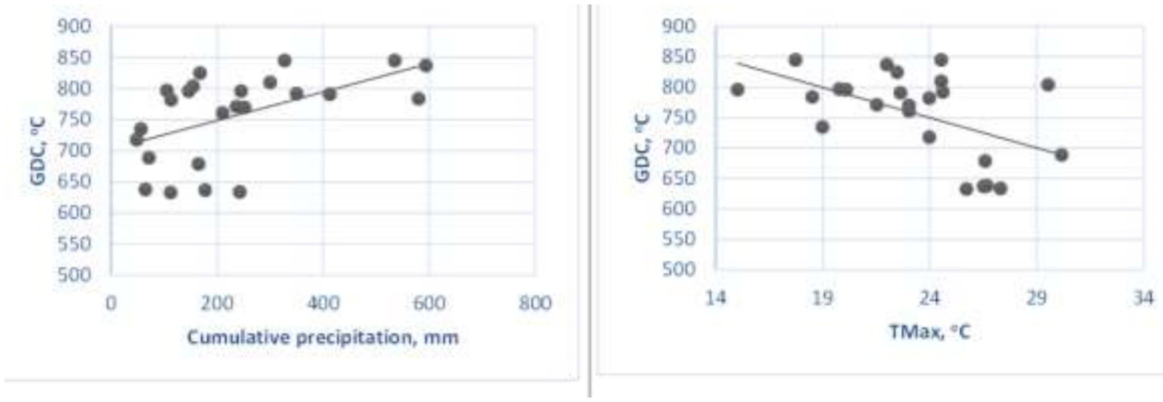

Figure 5. Beginning of flowering as a function of GDC, cumulative rainfall and maximum temperature (24 years). Note: GDC: maximum = 812, minimum = 633, average = 757. Rainfall: maximum = 595, minimum = 49, average = 236. TMax: maximum = 27, minimum = 15 average = 23. Source: Author, 2023.

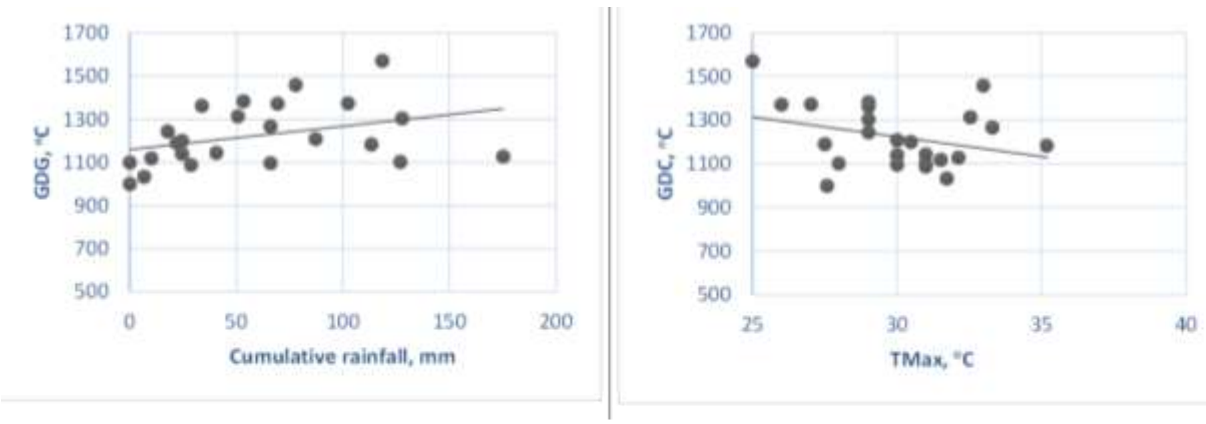

Figure 6. End of flowering as a function of GDC, cumulative rainfall and maximum temperature (24 years). Note: GDC: maximum = 1571, minimum = 1000, average = 1224. Rainfall: maximum = 75, minimum = 0, average = 60. TMax: maximum = 35, minimum = 25, average = 30. Source: Author, 2023.

The new varieties registered in the National Variety Catalog (in 2020), Elipse, Electra, Eleia, Eladir and Elfo confirm this situation, starting flowering earlier (with about 650 ºC accumulated), even with accumulated precipitation greater than 300mm during the Vegetative Period - between sowing and the beginning of flowering (Table 5), without floral abortion. These results were obtained in 4 years of testing (2016/17 to 2019/20) and the earlier ELEIA variety stands out at the beginning of flowering, it begins to produce flowers earlier but consequently reaches FF at 30 ºC, a date similar to the other varieties. This fact is also confirmed by the yields (kg/ha^{-1}) obtained in each variety in which ELEIA presents higher values than the others.

ELECTRA variety comes later in the FF, and the loss of yield was notable, in the very rainy 2019/20 year, in which excessive precipitation led to the seeds not set. Contrary to what was indicated, the ELFO variety is the latest to enter IF and the earliest at the end of the cycle; it is a Desi type of variety, with very short internodes (interval between flower nodes) and therefore obtaining a greater number of flowers and seeds. Currently, all the varieties registered by INIAV-Elvas in the National Catalogue of Varieties are precocious because they accelerate the beginning of flowering phase.

Table 5. Relation of GDC to IF and FF with yield per variety.

Varieties	GDC-IF (ºC)	GDC-FF (ºC)	Grain Yield (kg/ha^{-1})
ELIPSE	668	1281	1121
ELECTRA	684	1326	1228
ELEIA	660	1292	1542
ELADIR	701	1292	1180
ELFO	719	1271	1359

Note: GDC-IF: . GDC-FF: . Source: Author, 2023.

4. Conclusions

Given that we are going through a climate crisis and that Portugal has a typical Mediterranean climate, we have to be attentive to the development of plant material in the field as well as permanently, and not least, attentive to the meteorological data.

Chickpea, as an indeterminate type of crop, has the characteristic of growing whenever the humidity and temperature conditions are favourable (without excessive heat), so varieties that flower earlier have advantages over varieties that delay flowering cycle, as they can produce more flowers and consequently a greater number of pods and production. The phenological stages that the plants have throughout the cultural cycle is a good indicator (which farmers should be aware of) for predicting annual production.

5. Acknowledgments

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6. Auhors’ Contributions

Isabel Duarte: “Grain Legume Researcher” of National Institute of Agrarian and Veterinary Research (INIAV), Elvas, Portugal; Area of scientific activity: Genetics resources (pulses and pastures); Genetics breeding (pulses); Eco-physiological studies (pulses and pastures) and Phytopathological studies (pulses). Responsible for: design, experimental execution, data analysis, manuscript writing, submission, and layout, corrections design, experimental execution, data analysis, manuscript writing, submission, and layout corrections.

7. Conflicts of Interest

No conflicts of interest.

8. Ethics Approval

Not applicable.

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